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Research Article

The Critical Shoulder Angle: Acromial Coverage is More Relevant than Glenoid Inclination.†

Acromial Coverage determines the Critical Shoulder Angle

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AUTHOR CONTRIBUTIONS STATEMENT:

S.B, D.M and C.G conceived and planned the study. S.B and A.H did all the measurement and Data collection. A.H and S.B. contributed to the interpretation of the results. T.G made the statistical analysis. S.B and A.H took the lead in writing the manucript. All authors provided critical feedback and helped shaping the research, analysis and manuscript. All authors read and approved the final submitted manuscript.

Abstract:

It is still unknown whether glenoid inclination or lateral acromial roof extension is a more important determinant for development of rotator cuff tears (RCT) or osteoarthritis (OA) of the shoulder. It was the purpose of this study, to evaluate whether there is a potential predominance of one of these factors in pathogenesis of RCT or concentric OA. We analyzed 70 shoulders with advanced degenerative RCT and 54 shoulders with concentric OA undergoing primary shoulder arthroplasty (anatomical or reverse) using antero-posterior radiography and multiplanar computed tomography. The two groups were compared in relation to glenoid inclination, lateral acromion roof extension, acromial height and critical shoulder angle (CSA). All measured parameters were highly significantly different between RCT and concentric OA ($p<0.001$). Based on Cohen's d effect size, group differences were most distinct in lateral acromial roof extension ($1.36_{x\text{-}ray}$, 0.92_{ct}) compared with acromial height ($1.06_{x\text{-}ray}$, 0.73_{ct}) and glenoid inclination ($0.60_{x\text{-}ray}$, 0.61_{ct}). However, no single factor showed an effect size which was as high as that of the CSA ($1.63_{x\text{-}ray}$). Interestingly, a ratio of lateral acromion roof extension and acromial height could enhance the effect size ($1.60_{x\text{-}ray}$, 1.16_{ct}) near to values of the CSA ($1.63_{x\text{-}ray}$). In summary, lateral acromial roof extension has a greater influence in pathogenesis of degenerative RCT and concentric OA than acromial height or glenoid inclination. This article is protected by copyright. All rights reserved

Introduction:

The pathogenesis of rotator cuff tears (RCT) and osteoarthritis (OA) is still unknown, although similar genetic and environmental factors have been implicated in both conditions (1-3). Interestingly, the two pathologies – at least in their early stages – are rarely seen together (1). Therefore, different anatomical predispositions have been suspected to be linked with these two pathologies. Evidence for anatomical variants predisposing to either disease could only be demonstrated by the introduction of the Critical Shoulder Angle (CSA) in 2013 (1) and the understanding of its biomechanical implications (4-6). The CSA is a radiographic parameter and is measured in antero-posterior (A/P) radiographs as an angle between a line from the lower to the upper glenoid rim (glenoid plane) and a second line from the lower glenoid rim to the lateral edge of the acromion roof (1). High angles (>35-38°) was associated with RCT and biomechanical analyzation could show an increased joint instability (1). Otherwise, low angles (<28-30) was associated with OA and biomechanical analyzation could show an increased glenohumeral joint reaction force (1). The challenge consists now in the fact, that this angle is a combination of glenoid inclination, lateral acromial roof extension and acromial height. Because all three sub-parameters are linked, the hierarchy of relevance of the individual sub-parameters is very difficult – or even impossible – to prove! Particularly the measurement of lateral acromial roof extension and acromial height could be strongly distorted through the influence of glenoid inclination (Figure 1).

Today, arthroscopic reduction of the lateral acromial roof is already widely performed to reduce the radiological CSA towards "normal" values to prevent development of RCT (8-13) Although first clinical results could show a lower recurrent rupture of repaired RCT(12, 13), it is not clear whether it would be optimal to correct glenoid inclination, acromial height or lateral acromial roof extension to reduce the overload of the rotator cuff. It is therefore of great interest to identify the primary influencing factor.

The purpose of this study was to search a potential predominance of either glenoid inclination, lateral acromion roof extension or acromial height for distinguishing shoulders with degenerative RCT or concentric OA.

Methods:

We collected data of patients undergoing primary total shoulder arthroplasty (anatomical and reverse) because of advanced RCT or primary concentric OA from January 2006 until April 2017. During this period, 948 patients had prosthetic shoulder surgery. 67 patients (70 shoulders) with degenerative RCT and 44 patients (54 shoulders) with concentric OA fulfilled all inclusion and exclusion criteria. Excluded were all secondary reasons for RCT or OA, destructions of the glenoid (Favard ≥E1) (14) or acromion (Hamada ≥3 (15), previous acromioplasty), shoulders with glenoid version ≥15° and posterior/anterior subluxation of >65%/<35%. Detailed criteria are presented in Table 1.

Statistical explanation of sub-components:

We disassembled all three sub-components of the CSA; glenoid inclination (°), lateral acromial roof extension (mm) and acromial height (mm). For precise measurement, we used the "Merlin PACS Imagine Software" (Phönix-PACS GmbH, Freiburg i. Br., Germany) with its multi plane reconstruction (MPR) function. Hereby, adjustment in all three dimensions (3D) was possible and each part of interest could be highlighted individually.

- Critical Shoulder Angle (CSA) ($_{\text{x-ray}}$): Measured in A/P radiographs ($_{\text{x-ray}}$) as described by Moor (1). Angle between a line from the upper to the lower glenoid rim (= glenoid plane, Figure 2b) and a second line from the lower glenoid rim to the most lateral acromial extension.
- Glenoid inclination ($_{\text{x-ray / ct}}$): Measured as described as beta-angle by Maurer (17) in A/P radiographs ($_{\text{x-ray}}$) (Figure 3a) and in adjusted CT scans ($_{\text{ct}}$) (Figure 3d). Angle between a line from the upper to the lower glenoid rim (glenoid plane, Figure 2b) and a second line set on the floor of the supraspinous fossa. In CT scan, the coronal A/P view was adjusted to the scapular plane (Figure 2c). The scapular plane was defined in

sagittal CT scan, parallel to the scapular blade from the upper to the lower part of the blade.

- Lateral acromial roof extension ($_{\text{x-ray / ct}}$): Measured as a distance (mm) perpendicular to the glenoid plane to the most lateral acromion edge in A/P radiographs ($_{\text{x-ray}}$) (Figure 3b) and adjusted axial CT scans ($_{\text{ct}}$) (Figure 3e).
- Acromial height ($_{\text{x-ray / ct}}$): Measured in A/P radiographs ($_{\text{x-ray}}$) (Figure 3c) from the most inferior point of the glenoid to the undersurface of the acromial roof. In CT scans ($_{\text{ct}}$) (Figure 3f), the acromial height was defined from the glenoid centre to the undersurface of the most anterior, middle (central) and most posterior lateral acromion roof extension. The central lateral acromion roof extension was defined as the middle point between the most anterior and the most posterior lateral acromion roof extension, parallel to the glenoid plane (Figure 3f).

Statistical analysis:

Associations between interval scaled variables were analyzed using ordinary least square (OLS) simple linear regressions. All models contained a constant and one explanatory factor. Predictive value of the model was described by R-squared. Differences between groups were analyzed using independent samples t-test. Effect sizes were described using Cohen's d. p-values below 0.05 were considered statistically significant. Statistical analysis was performed with SPSS (IBM Corp. IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp.)

Results:

The two groups were similar in terms of age, height, weight, sex and side. Demographic data are listed in Table 2.

CSA, glenoid inclination, lateral acromial roof extension and acromial height were all highly significant different between RCT and concentric OA ($p<0.001$) (Table 3). For RCT, the mean CSA was 34.5°$_{x\text{-}ray}$, glenoid inclination 76.8°$_{x\text{-}ray}$ / 78.8°$_{ct}$, lateral acromial roof extension 35.2mm$_{x\text{-}ray}$ / 33.7mm$_{ct}$ and acromial height 52.4mm$_{x\text{-}ray}$ / anterior 35.6mm$_{ct}$ / central 35.2mm$_{ct}$ / posterior 40.3mm$_{ct}$. For concentric OA, the mean CSA was 27.4°$_{x\text{-}ray}$, glenoid inclination 81.2°$_{x\text{-}ray}$ / 82.0°$_{ct}$, lateral acromial roof extension 29.4mm$_{x\text{-}ray}$ / 29.9mm$_{ct}$ and acromial height 58.7mm $_{x\text{-}ray}$ / anterior 38.3mm$_{ct}$ / central 38.2mm$_{ct}$ / posterior 42.6mm$_{ct}$. Linear regression analysis indicated a significant positive association of CSA with lateral acromial roof extension and a significant negative association with glenoid inclination and acromial height. All data of RCT and concentric OA group are illustrated in Table 3 and 4.

Analysis of the effect size (Cohen's d) can be interpreted as weak (value of 0.2-0.5), intermediate (0.5-0.8) or strong (>0.8) association(18). The group difference was most distinct in lateral acromial roof extension (1.36$_{x\text{-}ray}$, 0.92$_{ct}$) while being smaller in acromial height (1.06$_{x\text{-}ray}$, 0.73$_{ct}$) and glenoid inclination (0.60$_{x\text{-}ray}$, 0.61$_{ct}$). Acromial height in CT had the best effect size if measured centered to the acromial roof (0.73$_{ct}$) and only weak if measured with regard to the posterior acromial edge (0.39$_{ct}$). Strongest effect size could be found for the CSA in A/P radiographs (1.63$_{x\text{-}ray}$). The ratio of lateral acromial roof extension / acromial height increased the effect size in radiographs (from 1.36$_{x\text{-}ray}$ and 1.06$_{x\text{-}ray}$ to 1.60$_{x\text{-}ray}$) and in CT (from 0.92$_{ct}$ and 0.73$_{ct}$ to 1.16$_{ct}$). All values are listed in Table 3.

Discussion:

High CSA and large lateral acromial roof extension, as well as low glenoid inclination and low acromial height, were more likely to be associated with RCT rather than concentric OA. With the effect size Cohen's d, we found a superiority of the lateral acromial roof extension in A/P radiographs ($1.36_{\text{x-ray}}$) and CT (0.92_{ct}). While acromial height ($1.06_{\text{x-ray}}$, 0.73_{ct}) also showed a strong effect size, glenoid inclination ($0.60_{\text{x-ray}}$, 0.61_{ct}) was only of intermediate relevance.

Interestingly, none of the three sub-components achieved similarly good predictive results as the CSA alone ($1.63_{\text{x-ray}}$). Only by creating a ratio between lateral acromial roof extension and acromial height, the effect size could be increased ($1.36_{\text{x-ray}}$ and $1.06_{\text{x-ray}}$ to $1.6_{\text{x-ray}}$) to nearly as good values as with the CSA in A/P radiographs and CT (0.92_{ct} and 0.73_{ct} to 1.2_{ct}). This means, that the negative impact of a large lateral acromial roof extension for the development of RCT could be increased by concomitant low acromial height. An arithmetic model could explain their relationship (Figure 4). If the acromial height was measured from the inferior glenoid rim (parallel to the glenoid plane) to the undersurface of the lateral border of the acromion, and the lateral acromial roof extension (perpendicular to the glenoid plane) to the lateral border of the acromion, their relation to the CSA would only differ by the tangent function of this ratio (Figure 4).

All values had a stronger effect size if measured in A/P radiography compared to the CT scan. We did not find a convincing explanation for this over- or under-estimation. Acromial height was measured in CT scan from the glenoid center and not from the inferior glenoid rim to the undersurface of the acromial roof. Further, while in CT scan individual adjustment was possible at any time, measurement in A/P radiographs was influenced by the initial settings of the radiographer. But whether all these inaccuracy factors of A/P radiographs should increase the effect size, is strange and seems illogical.

But a similar phenomenon was observed already by Spiegl (19). The CSA showed a higher correlation in A/P radiographs compared to MRI scans.

There are several limitations. We do not have a “normal” control group. Therefore, we can only analyze the three sub-components according to RCT and OA. Two of the sub-components have absolute values. Particularly anatomical differences in scapula size between small and tall people or between woman and men may influence absolute values. These could be reduced by the fact that both groups do not differ according to gender, patient height or weight.

Moor et al (1) found the CSA as the most valuable parameter for discriminating between RCT and OA compared with Acromion Index (AI) (2) and Lateral Acromion Angle (LAA) (16). The AI is a ratio between the distance from the glenoid plane to the lateral acromion edge and the distance from the glenoid plane to the lateral edge of the humeral head in A/P radiographs. Therefore, it is mostly influenced by the lateral extension of the acromial roof and humeral head. Otherwise, the LAA is measured as an angle between the glenoid plane and a fitting line at the undersurface of the acromion in A/P radiographs (16). And in relation to the CSA, mostly influenced by glenoid inclination. Because they found an excellent correlation between CSA and AI ($r=0.895$; $p<0.001$) and only moderate correlation for LAA ($r = -0.551$; $p<0.001$), they concluded that the lateral acromial roof extension represents a more relevant risk factor for rotator cuff disease than an upward tilt of the glenoid fossa. But it is unknown whether the LAA is a reliable value to determine glenoid inclination or only to measure an upward or downward tilt of the acromial roof itself. Otherwise, in 2015, Daggett (7) found a high correlation between glenoid inclination, measured with the beta-angle of Maurer (17) and the CSA ($r=0.743$; $p<0.001$) in patients with RCT and OA. Therefore, they concluded that glenoid inclination could be the main influencing factor and increased or decreased lateral acromial roof extension would be changed by up-ward or down-ward tilt of the glenoid plane (Figure 1).

Compared to these studies above, we examined glenoid inclination, lateral acromial roof extension and acromial height. And according to the effect size, lateral acromial roof extension seems to be the strongest influencing factor for distinction between RCT and OA. There is a great interest to change the radiological CSA towards to “normal” values and thereby reducing an overload of the rotator cuff. Although it has not yet been clarified which sub-component (glenoid inclination, lateral acromial roof extension, acromial height) has the greatest impact, arthroscopic lateral acromioplasty is already performed (8-13). Our data could support lateral acromioplasty. But nevertheless, an assessment about the effectiveness and necessity of lateral acromioplasty cannot be investigated by this study. Further investigations are needed.

Conclusion:

Glenoid inclination, lateral acromial roof extension and acromial height are significantly different between RCT and concentric OA ($p<0.001$). Of all three sub-components, lateral acromial roof extension was superior and glenoid inclination had weakest effect size in Cohen's d test for distinction between RCT and concentric OA. However, none of the three sub-components had an effect size as strong as the CSA. Interestingly, the ratio of lateral acromial roof extension and acromial height could improve the effect size to nearly equal good values as with the CSA alone. Measurement in A/P radiographs showed better effect sizes than in adjusted CT.

This study supports the possibility of lateral acromioplasty for influencing of the most relevant single sub-component of CSA. Nevertheless, an assessment about the effectiveness and necessity of lateral acromioplasty couldn't be done with this data. Further clinical and biomechanical investigations are needed.

References:

1. Moor BK, Bouaicha S, Rothenfluh DA, Sukthankar A, Gerber C. Is there an association between the individual anatomy of the scapula and the development of rotator cuff tears or osteoarthritis of the glenohumeral joint?: A radiological study of the critical shoulder angle. The bone & joint journal. 2013;95-B(7):935-41.
2. Nyffeler RW, Werner CM, Sukthankar A, Schmid MR, Gerber C. Association of a large lateral extension of the acromion with rotator cuff tears. The Journal of bone and joint surgery American volume. 2006;88(4):800-5.
3. Via AG, De Cupis M, Spoliti M, Oliva F. Clinical and biological aspects of rotator cuff tears. Muscles Ligaments Tendons J. 2013;3(2):70-9.
4. Gerber C, Snedeker JG, Baumgartner D, Viehofer AF. Supraspinatus tendon load during abduction is dependent on the size of the critical shoulder angle: A biomechanical analysis. J Orthop Res. 2014;32(7):952-7.
5. Viehofer AF, Gerber C, Favre P, Bachmann E, Snedeker JG. A larger critical shoulder angle requires more rotator cuff activity to preserve joint stability. J Orthop Res. 2016;34(6):961-8.
6. Viehofer AF, Snedeker JG, Baumgartner D, Gerber C. Glenohumeral joint reaction forces increase with critical shoulder angles representative of osteoarthritis-A biomechanical analysis. J Orthop Res. 2016;34(6):1047-52.
7. Daggett M, Werner B, Collin P, Gauci MO, Chaoui J, Walch G. Correlation between glenoid inclination and critical shoulder angle: a radiographic and computed tomography study. Journal of shoulder and elbow surgery / American Shoulder and Elbow Surgeons [et al]. 2015;24(12):1948-53.
8. Marchetti DC, Katthagen JC, Mikula JD, Montgomery SR, Tahal DS, Dahl KD, et al. Impact of Arthroscopic Lateral Acromioplasty on the Mechanical and Structural Integrity of

the Lateral Deltoid Origin: A Cadaveric Study. Arthroscopy : the journal of arthroscopic & related surgery : official publication of the Arthroscopy Association of North America and the International Arthroscopy Association. 2017;33(3):511-7.

9. Katthagen JC, Marchetti DC, Tahal DS, Turnbull TL, Millett PJ. The Effects of Arthroscopic Lateral Acromioplasty on the Critical Shoulder Angle and the Anterolateral Deltoid Origin: An Anatomic Cadaveric Study. Arthroscopy-the Journal of Arthroscopic and Related Surgery. 2016;32(4):569-75.

10. Karns MR, Jacxsens M, Uffmann WJ, Todd DC, Henninger HB, Burks RT. The critical acromial point: the anatomic location of the lateral acromion in the critical shoulder angle. Journal of shoulder and elbow surgery / American Shoulder and Elbow Surgeons [et al]. 2018;27(1):151-9.

11. Heuberer PR, Plachel F, Willinger L, Moroder P, Laky B, Pauzenberger L, et al. Critical shoulder angle combined with age predict five shoulder pathologies: a retrospective analysis of 1000 cases. BMC musculoskeletal disorders. 2017;18(1):259.

12. Gerber C, Catanzaro S, Betz M, Ernstbrunner L. Arthroscopic Correction of the Critical Shoulder Angle Through Lateral Acromioplasty: A Safe Adjunct to Rotator Cuff Repair. Arthroscopy : the journal of arthroscopic & related surgery : official publication of the Arthroscopy Association of North America and the International Arthroscopy Association. 2017.

13. Garcia GH, Liu JN, Degen RM, Johnson CC, Wong AC, Dines DM, et al. Higher critical shoulder angle increases the risk of retear after rotator cuff repair. Journal of shoulder and elbow surgery / American Shoulder and Elbow Surgeons [et al]. 2017;26(2):241-5.

14. Sirveaux F, Favard L, Oudet D, Huquet D, Walch G, Mole D. Grammont inverted total shoulder arthroplasty in the treatment of glenohumeral osteoarthritis with massive

rupture of the cuff. Results of a multicentre study of 80 shoulders. J Bone Joint Surg Br. 2004;86(3):388-95.

15. Hamada K, Fukuda H, Mikasa M, Kobayashi Y. Roentgenographic findings in massive rotator cuff tears. A long-term observation. Clin Orthop Relat Res. 1990(254):92-6.

16. Banas MP, Miller RJ, Totterman S. Relationship between the lateral acromion angle and rotator cuff disease. Journal of shoulder and elbow surgery / American Shoulder and Elbow Surgeons [et al]. 1995;4(6):454-61.

17. Maurer A, Fucentese SF, Pfirrmann CW, Wirth SH, Djahangiri A, Jost B, et al. Assessment of glenoid inclination on routine clinical radiographs and computed tomography examinations of the shoulder. Journal of shoulder and elbow surgery / American Shoulder and Elbow Surgeons [et al]. 2012;21(8):1096-103.

18. J. C. Statistical power analysis for the behavioral sciences. Second Edition ed. Hillsdale: Lawrence Erlbaum Associates; 1988.

19. Spiegl UJ, Horan MP, Smith SW, Ho CP, Millett PJ. The critical shoulder angle is associated with rotator cuff tears and shoulder osteoarthritis and is better assessed with radiographs over MRI. Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA. 2016;24(7):2244-51.

Figure and tables legends:

Figures:

Figure 1: Influence of CSA, Roof, Height and LAA by changing of GI.

a) Shoulder model with supraspinous fossa (dark blue bar), glenoid plane (red bar), acromial roof (green bar). GI (= glenoid inclination), CSA (= critical shoulder angle), LAA (= lateral acromial angle), Roof (= lateral acromial roof extension), Height (= acromial height)
b) Isolated modification of GI can influence CSA, Roof, Height and LAA, if measured parallel to the glenoid plane. In this example with up-ward tilting of the glenoid plane, CSA and Roof increases by simultaneous decreasing of LAA and Height.

Figure 2 a-c: Lateral acromial roof: glenoid plane and scapular plane

a) Lateral acromial roof (red)
b) Glenoid plane (yellow)
c) Scapular plane (green)

Figure 3a-f: Measurement parameters on A/P x-ray and CT

a-c) Measurement methods on A/P x-ray: glenoid inclination, lateral acromial roof extension and acromial height.

d-f) Measurement methods on CT: glenoid inclination, lateral acromial roof extension and acromial height.

Figure 4a-b: Relationship of lateral acromial roof extension (=Roof) / acromial height (=Height) and CSA:

a) Three different acromion roofs with different lateral acromial roof extension (= Roof 1, 2, 3) and different acromial height (= Height 1, 2, 3), but equal CSA. Ratio of Roof 1 / Height 1 is equal to Roof 2 / Height 2 and Roof 3 / Height 3.

b) Association between lateral acromial roof extension (= Roof, a), acromial height (= Height, b) and CSA. Tangent function of the calculated CSA is equal to the ratio of Roof/Height.

Tables:

Table 1: Inclusion and exclusion criteria		
	Rotator Cuff Tear Group (RCT) *(n = 70 shoulder)*	**Osteoarthritis Group (COA)** *(n = 54 shoulder)*
Inclusion Criteria	• Degenerative rotator cuff tear • Preoperative X-rays and CT scans	• Primary concentric osteoarthritis • Preoperative X-rays and CT scans
Exclusion Criteria	• Glenoid version >15° • Concomitant OA • Destruction of the acromion (Hamada ≥3, previous acromioplasty) • Destruction of the glenoid (Favard ≥E1) • Secondary: traumatic / fracture / malunion, osteonecrosis, infection, instability, rheumatoid, chondrocalcinosis, hemophilia	• Concomitant rotator cuff tear • Posterior subluxation (>65% / <35%), Eccentric (>15° glenoid version) / Walch ≥B • Destruction of the acromion (previous acromioplasty) • Massive destruction of glenoid • Secondary: traumatic / fracture / malunion, osteonecrosis, infection, instability, rheumatoid, chondrocalcinosis, hemophilia

Table 2: Demographic data

	Rotator Cuff Tear Group (RCT) *(n = 70 shoulder)*	Osteoarthritis Group (COA) *(n = 54 shoulder)*	p value
Age	Mean 72.3 years (56-85), SD 6.7, Median 72.5 years	Mean 71 years (57-86), SD 7.8, Median 70 years	0.745
Height	Mean 165.7 cm (146-186), SD 9.5, Median 165 cm	Mean 163.8 cm (142-195), SD 10.3, Median 165 cm	0.174
Weight	Mean 75.4 kg (46-130), SD 16.5, Median 75 kg	Mean 75.3 kg (46-106), SD 15.4, Median 73 kg	0.733
Sex	Women 44, Men 26	Women 38, Men 17	0.512
Side	Right 40, Left 30	Right 29, Left 26	0.947
Tear pattern	Antero-superior tear 12 Postero-superior tear 44 Antero-supero-posterior tear 14	No tear	

Table 3: Descriptive values, correlations between RCT and COA, Cohen's d							
	RCT		***COA***				
	Mean *(Range)*	***SD***	***Mean*** *(Range)*	***SD***	***p-value***	***SED***	***Cohen's d***
X-ray							
CSA *(°)*	*34.5 (22-47)*	*4.3*	*27.4 (17-37)*	*4.4*	*0.000*	*0.78*	*1.63*
Inclination *(°)*	*76.8 (37-89)*	*8.5*	*81.2 (68-89)*	*5.6*	*0.001*	*1.34*	*0.60*
Roof *(mm)*	*35.2 (27-44)*	*3.8*	*29.4 (16-41))*	*4.8*	*0.000*	*0.78*	*1.36*
Height *(mm)*	*52.4 (40-70)*	*6.3*	*58.7 (47-73)*	*5.7*	*0.000*	*1.09*	*1.06*
Roof/Height *()*	*0.68 (0.4-1.1)*	*0.1*	*0.5 (0.3-0.7)*	*0.1*	*0.000*	*0.02*	*1.60*
CT							
Inclination *(°)*	*78.8 (57-89)*	*5.6*	*82.0 (70-89)*	*5.0*	*0.001*	*0.96*	*0.61*
Roof *(mm)*	*33.7 (25-47)*	*4.1*	*29.9 (19-40)*	*4.3*	*0.000*	*0.76*	*0.92*
Height							
- anterior (mm)	*35.6 (33.5-36.1)*	*3.8*	*38.3 (37.1-39.2)*	*4.1*	*0.000*	*0.71*	*0.68*
- central (mm)	*35.2 (33.9-35.9)*	*4.7*	*38.2 (36.7-39.9)*	*3.6*	*0.000*	*0.76*	*0.73*
- posterior (mm)	*40.3 (38.5-41.4)*	*6.6*	*42.6 (40.3-43.6)*	*5.0*	*0.034*	*1.08*	*0.39*
Roof/Height$_c$ *()*	*0.96 (0.92-1.01)*	*0.2*	*0.79 (0.76-0.81)*	*0.1*	*0.000*	*0.03*	*1.16*

CSA (= Critical Shoulder Angle), Roof (= lateral acromial roof extension), Height (= acromial height), Height$_c$ (acromial height; central measurement) SD (= Standard Deviation), SED (= Standard Error Difference)

Table 4: Associations of CSA with lateral acromial roof extension (Roof), glenoid inclination (Inclination) and acromial height (Height)

	Slope	***P-value***	***Rsquare***
x-ray			
Roof	*0.770*	*<0.001*	*0.689*
Height	*-0.886*	*<0.001*	*0.532*
Inclination	*-0.561*	*<0.001*	*0.165*
CT			
Roof	*0.557*	*<0.001*	*0.454*
Height			
- anterior	*-0.343*	*<0.001*	*0.213*
- central	*-0.299*	*<0.001*	*0.138*
- posterior	*-0.232*	*<0.018*	*0.046*
Inclination	*-0.334*	*<0.001*	*0.111*

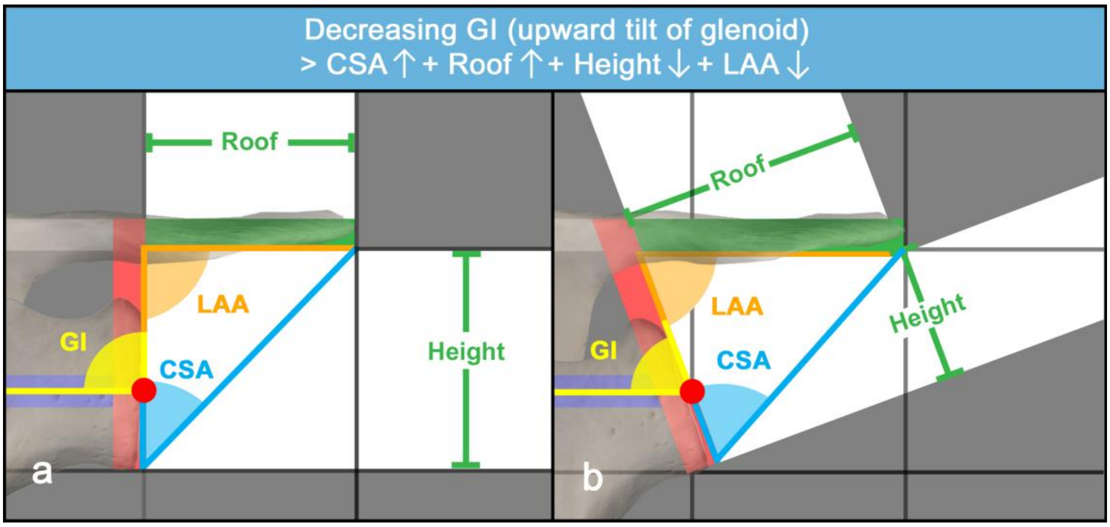

Decreasing GI (upward tilt of glenoid)
> CSA↑ + Roof↑ + Height↓ + LAA↓
Roof
LAA
GI
CSA
Height
a
Roof
LAA
GI
CSA
Height
b

Figure 1

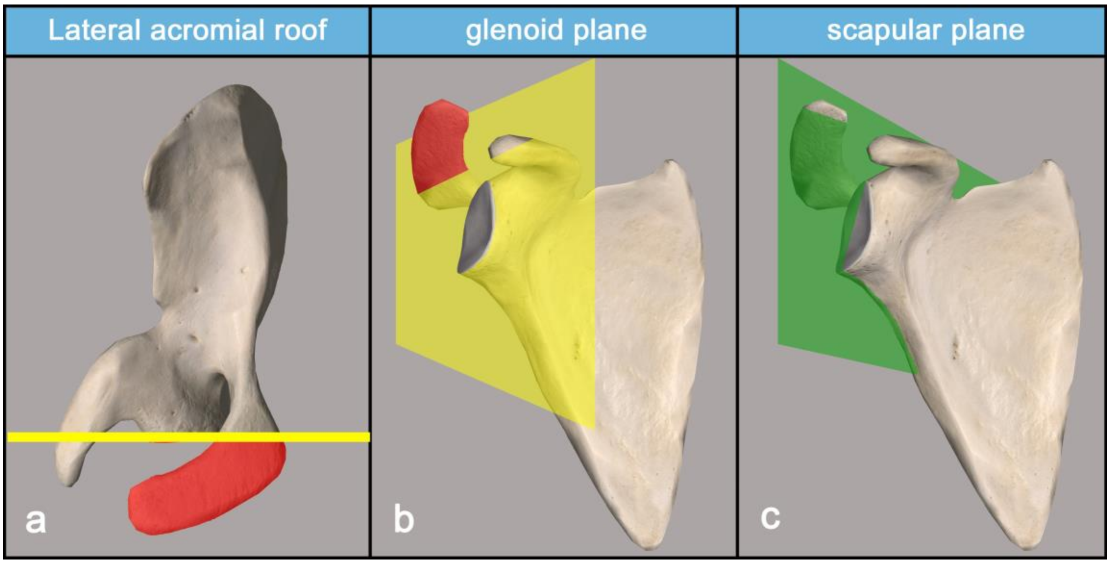
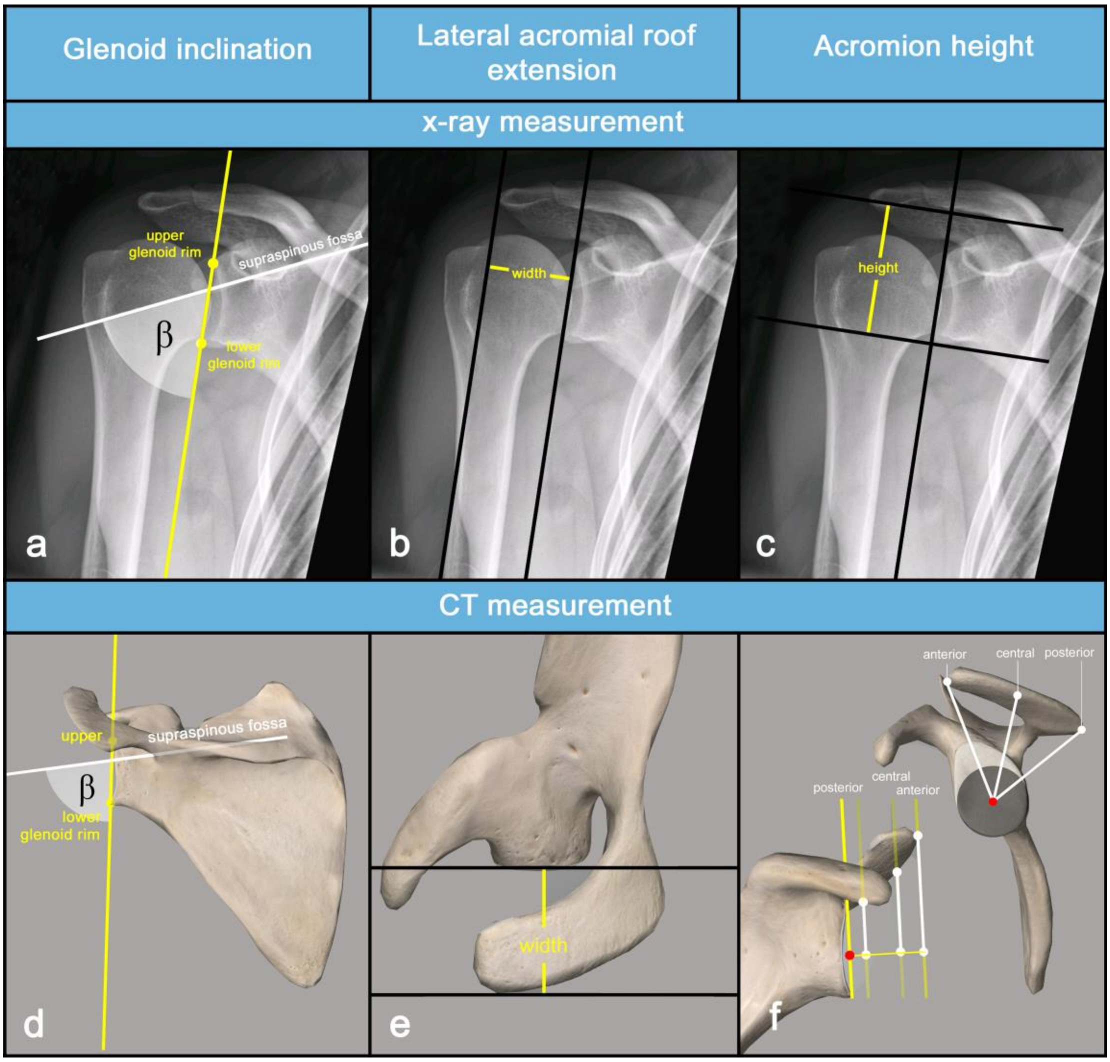


Figure 2



Glenoid inclination
Lateral acromial roof extension
Acromion height
x-ray measurement
upper glenoid rim
supraspinous fossa
β
lower glenoid rim
a
width
b
height
c
CT measurement
upper
supraspinous fossa
β
lower glenoid rim
d
width
e
anterior
central
posterior
posterior
central
anterior
f

Figure 3

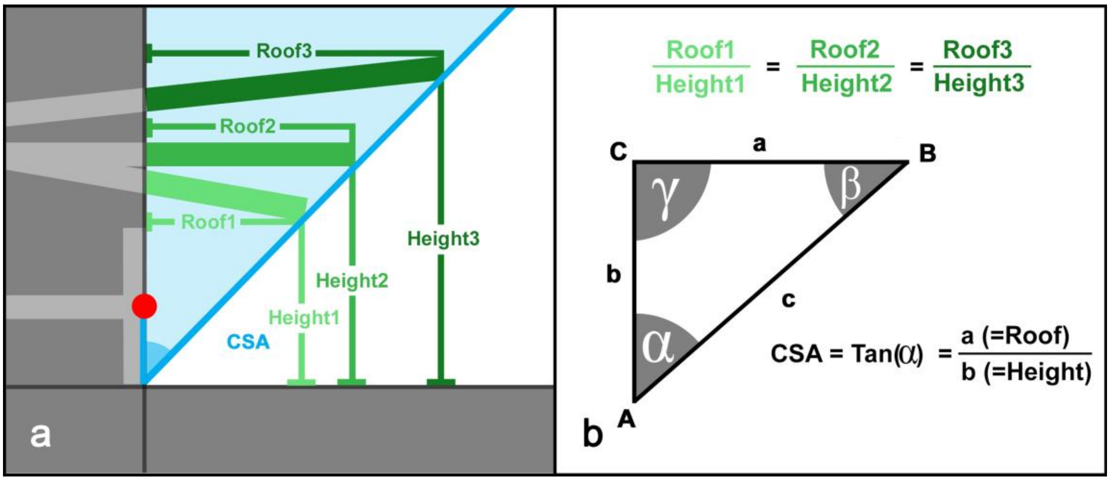

Roof3
Roof2
Roof1
Height3
Height2
Height1
CSA
a
Roof1 / Height1 = Roof2 / Height2 = Roof3 / Height3
C
a
B
γ
β
b
c
α
CSA = Tan(α) = a (=Roof) / b (=Height)
b
A

Figure 4